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EP 0122489 A1 EP 0113461 A2 EP 0055319 A1

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INT CL^5 **G08B 17/103 17/107**

(54) Proportional light scattering sensor for particles

(57) In a light scattering sensor for detecting particles in air e.g. smoke from a fire, radiation reaches receiver 3 from source 1 by a direct path 5, and from source 2 either by scattering or reflection from the surfaces 4 or due to airborne particles. The ratio of the radiation outputs from sources 1 and 2 is accurately controlled by electronic means 8 and 9, such that the signal received from source 1 is substantially equal to the standing scatter level signal from source 2 via surface 4. Difference signals or ratio changes are due to particles, and it is these rather than the absolute signal levels which are used to sense the particle concentration. Advantages include that a high sensitivity may be achieved in the presence of a relatively large standing scatter level, the sensitivity is largely unaffected by drifts and contamination, and differences in radiation scattering as function of position, wavelength or angle may be more readily employed.

Figure 1

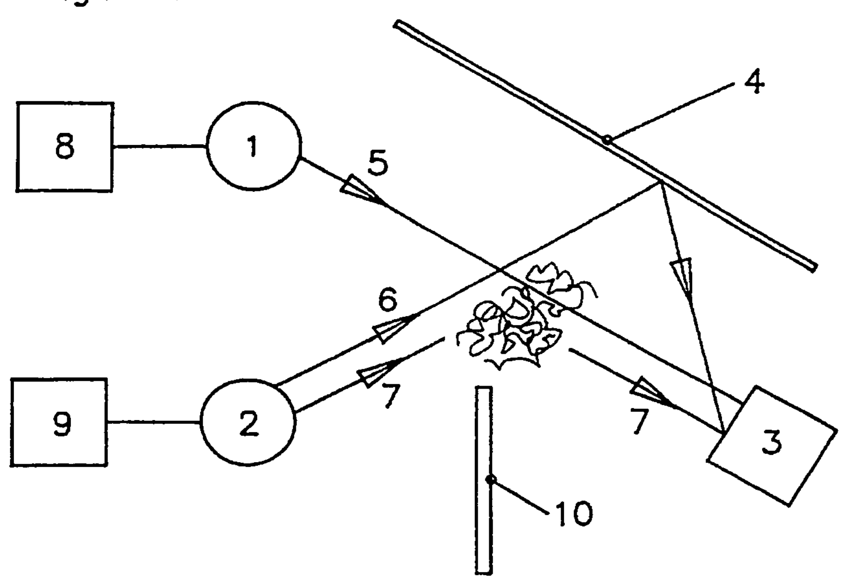

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Figure 1

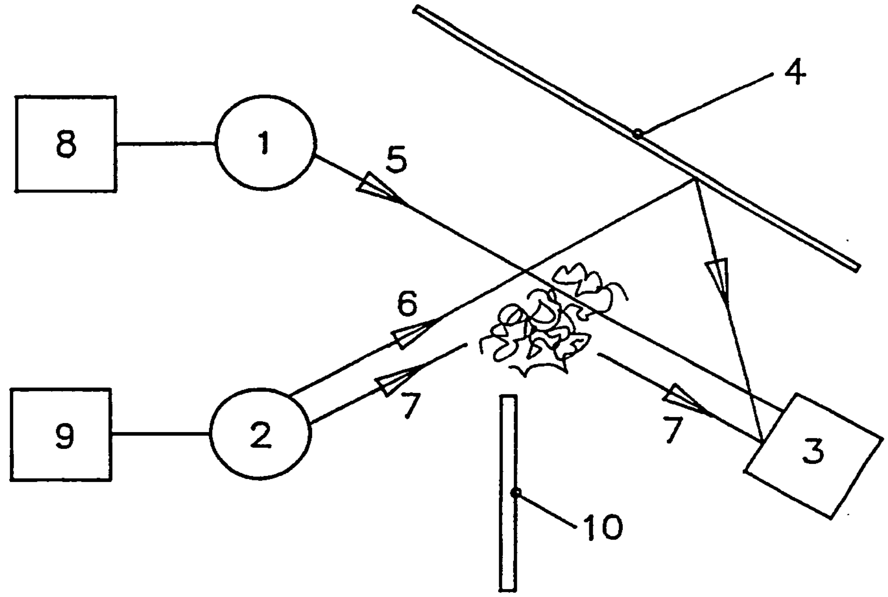


Figure 2

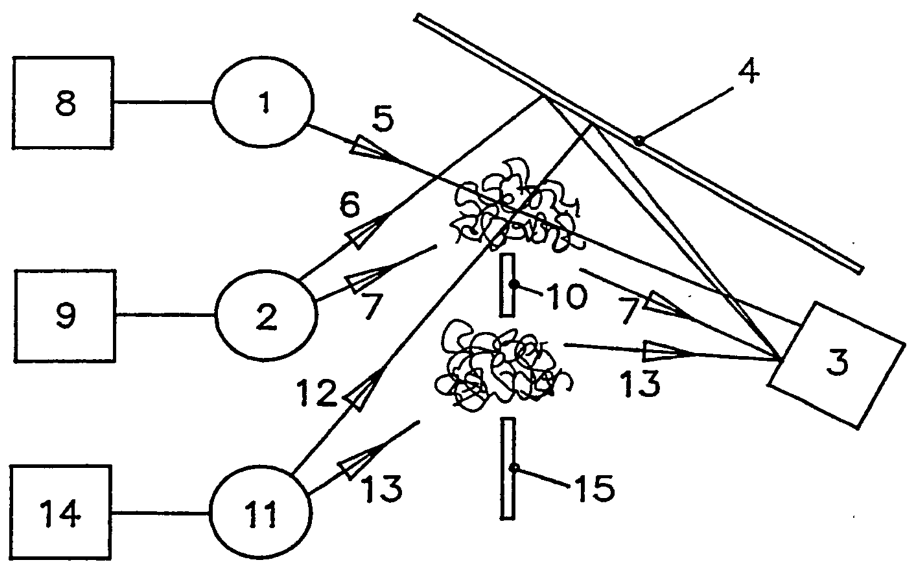


Figure 3

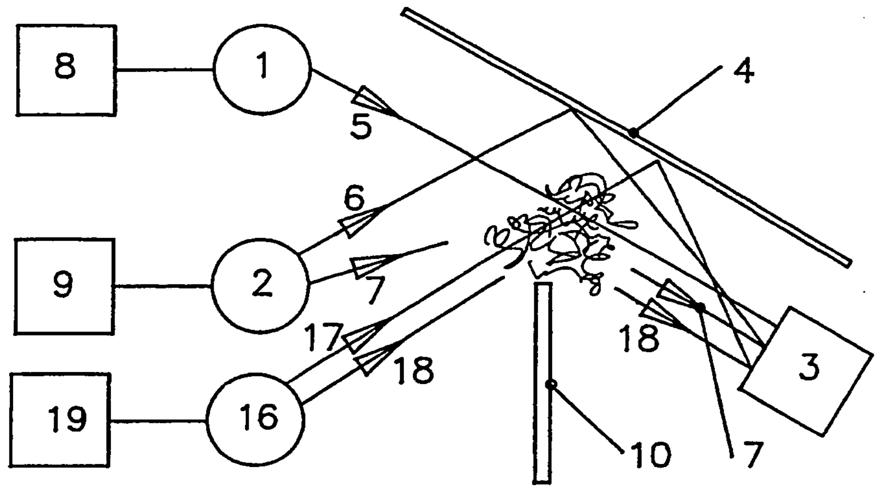
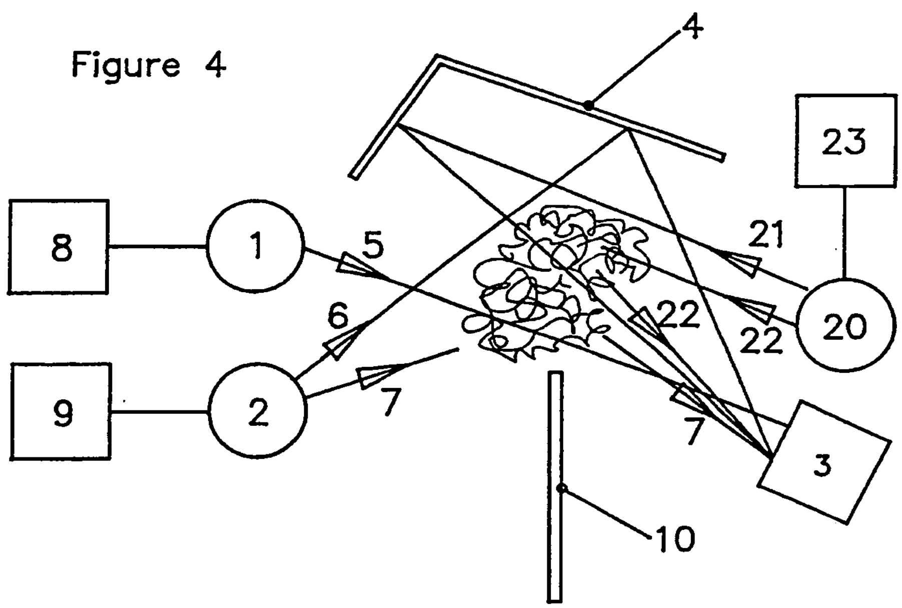


Figure 4



PROPORTIONAL LIGHT SCATTERING SENSOR

This invention relates to improved light scattering sensors suitable for sensing the presence of particles in air, such as smoke resulting from a fire.

It is well known that the presence of smoke may be sensed by means of the quantity of electromagnetic radiation in the visible or near infra-red wavebands (light) scattered or reflected by the smoke particles. Two types of smoke detector using this mechanism are in widespread use.

One type of detector is the so called point smoke detector. Point smoke detectors are generally mounted on the ceiling of a protected space. They sample part of any airflow past the detector through a mesh to exclude insects, and then through the sensing chamber. A light emitting diode source emits pulses of near infra-red radiation into the chamber. Smoke particles scatter or reflect a very small proportion of this radiation, and the scattered radiation is sensed by a receiver, mounted so that it does not receive radiation from the source by a direct path. The sensitivity is typically set for a smoke alarm threshold corresponding to about 0.1dB/m of radiation obscuration. The detailed design of sensor and sensing chamber varies from instance to instance. Formerly a scatter angle of 90 degrees was often used, although more recently shallow forward scatter angles (eg 45 degrees) are employed, which are found to offer a good level of sensitivity together with a convenient mechanical arrangement of the source and the receiver. Detectors using a backwards scatter angle of approximately 180 degrees are also known.

Another type of smoke detector is the so called aspirating (or active sampling, or high sensitivity) smoke detector, which may be mounted either local to, or remote from the protected space. The air is drawn from the space via pipework with the aid of a fan or pump, filtered, and then passed through the sensing chamber. Since any sampled smoke from the space may be very diluted with air the radiation scattering sensor usually has a much higher sensitivity than that in a typical point smoke detector (typically corresponding to about 0.001dB/m). This level of sensitivity is often achieved by using high intensity or well collimated radiation sources (eg xenon flash tubes or infra-red laser diodes), together with more complicated optical arrangements.

With point smoke detectors, the light scattering sensor previously described uses low cost source and receiver components, is easy to manufacture, and generally works well for the intended application. The shallow forward scatter angle provides for an efficient transfer of energy from the source to the receiver for the wide range of particle properties found in different types of smokes. Effective

operation is therefore possible with a very low input of energy to the source (typically < 1mW).

A disadvantage with this sensor is that the absolute sensitivity to smoke is difficult to set up in manufacture, and subsequently to maintain during life. There would be a significant benefit in being able to monitor and correct for sensitivity variations, apart from the obvious improvement in terms of safety and reduced maintenance costs.

For a given sensing chamber geometry the two main unknowns which affect the energy transfer, and therefore the sensitivity to smoke, are the efficiency of radiation emission of the source and the efficiency of the receiver. Both of these are susceptible to drifts in the electro-optical components themselves and in their associated electronic circuitry, for example as a result of ageing or temperature effects. The coating of the optical surfaces by atmospherically borne contaminants during the lifetime of the sensor is also a major consideration.

It is known that a second reference radiation source with a direct radiation path to the receiver may be used to functionally monitor for the operation of the receiver. Similarly, it is also known that a second reference receiver, with a direct radiation path from the main source, may be used to functionally monitor for the operation of the main source. In principle, these techniques could be combined to quantitatively monitor the efficiencies of both the main source and the receiver. However, the use of a second receiver would add significantly to the manufacturing cost of the sensor, and in order to achieve the desired benefits great care would also be necessary with the stability of the optical arrangement, and with matching and maintaining the gains and linearities of the sources and receivers and their associated electronics.

An alternative known method for functionally monitoring the operation of the source and the receiver is to use a low standing level of radiation, scattered or reflected from the internal surfaces of the chamber enclosure. This feature may be deliberately included in the chamber design. However, this feature cannot normally be used to quantitatively measure the sensitivity, because of the difficulty in scattering or reflecting a very small constant proportion of the incident radiation, and because the standing level itself may be very significantly increased or decreased by atmospherically borne contaminants. Increasing the standing level to significantly higher level than that corresponding to the smoke alarm threshold would help, but this would only be practical if the sensor's resolution and sensitivity stability were sufficient not to affect the sensitivity to smoke, and not to risk causing false alarms.

With aspirating smoke detectors, there would be significant benefits in terms of power consumption and cost in using a

similar design of light scattering sensor to that used in point smoke detectors.

Were it also possible to accurately monitor the efficiency of the source and receiver it would be practical to employ techniques such as analysing the quantity of radiation scattered at more than one wavelength, or at more than one angle, in order to estimate the distribution of particle sizes and therefore better discriminate smoke from dust. It would also become possible to tolerate a relatively much higher standing level. With a higher smoke sensitivity the standing level becomes more significant in relationship to the alarm threshold, and is difficult to reduce it below a certain level without making the chamber unacceptably large.

It is an object of the present invention to provide for improved stability in light scattering sensors by the use of a proportional method of operation, with particular application to detecting smoke from fires, and thereby to make possible the use of techniques which improve the reliability and performance and reduce the manufacturing costs of such sensors.

According to the present invention there is provided a radiation scattering sensor for sensing the presence of particles in air within a partially enclosed chamber, characterised in that at least two sources and one receiver are disposed such that radiation emitted by a first source reaches a receiver predominantly via a direct path through the chamber and radiation emitted by a second source reaches the same receiver predominantly by means of scattering or reflection from inner surfaces of the chamber enclosure or due to particles present within a part of the chamber, and wherein the ratio of the radiation output from the first and second sources may be adjusted such that the signal received from the first source is substantially equal to that proportion of the signal received from the second source which derives from radiation scattered or reflected from the said surfaces.

The invention will now be described by way of example with reference to the accompanying drawing, in which:

- Figure 1 shows the basic arrangement of a sensor using two sources;
- Figure 2 shows an arrangement using three sources, in which radiation is scattered to the receiver from different parts of the chamber;
- Figure 3 shows an arrangement using three sources, in which radiation is emitted at different wavelengths;
- Figure 4 shows an arrangement using three sources, in which radiation is scattered through different angles.

As shown schematically in Figure 1, a reference source 1 emits radiation which travels to a receiver 3 along a predominantly direct path 5. Another source 2 emits radiation which reaches the receiver 3 along paths 6

predominantly by means of scattering or reflection from inner surfaces of the chamber enclosure 4, or along paths 7 due to particles, for example of smoke, present within a part of the chamber. It should be noted that it is not precluded that a proportion of the radiation reaching receiver 3 from source 1 is also scattered or reflected from surface 4. A barrier 10 prevents radiation from reaching the receiver 3 by a direct path from source 2. The radiation outputs from the sources 1 and 2 are controlled by electronic means 8 and 9. Either or both of these may be adjusted to make the signal received from source 1 substantially equal to that proportion of the signal which is received from source 2 along paths 6.

In the quiescent state, ie with few particles in the chamber and no significant scattering of radiation along paths 7, the signals at the receiver 3 are almost equal. As long as the amounts of radiation transmitted along paths 5 and 6 are either relatively unaffected, or are similarly influenced by environmental effects the signal equality at the receiver 3 will not change. Small differences in the signal sensed by the receiver 3 will therefore be mainly due to scattering from particles within the chamber, and the size of the difference as a proportion of the total signal received along path 5 is a quantitative measure of this.

The effect is that the sources and the receiver may be fully monitored. It also enables variations in the absolute radiation outputs of the sources or the efficiency of the receiver due to temperature changes, surface contamination or ageing not to affect the basic stability of the sensor. The optics and electronics can be so designed that the above factors have equal and opposite effects on the two sources and therefore do not affect the ratio required to maintain the received signal levels equal.

The presence of particles within the chamber will also tend to cause reductions in the radiation transmitted along paths 5 and 6, due to scattering and absorption. However, the geometry and path lengths of the sensor and the proportions of the incident radiation scattered or reflected from the surface 4 may be so arranged that the attenuation effects are small as compared with the increase along path 7, or even slightly enhance the signal difference sensed by the receiver 3.

Because of this proportional mode of operation, the sensor may be made largely self-calibrating, as well as being functionally monitored. Moreover, it may be arranged that for a surface 4 which has been newly manufactured, or is otherwise in a clean state, the proportion of the incident radiation scattered or reflected is in a known relationship to that scattered or reflected by a known concentration of particles having known properties. This feature may be used to calibrate the initial sensitivity of the sensor.

The scattering or reflection due to particles is assumed to be a proportion of that from surface 4, and that from the surface 4 is itself likely to change slowly during the lifetime of the sensor. The sensor is therefore in principle only capable of detecting when changes occur in the scattering or reflection due to particles, and not absolute levels. Since the time constant for significant changes in the properties of surface 4 will be relatively long (typically months or years), this presents no problems for its use for many particle sensing applications, including for fire detection. For those applications where absolute levels must be monitored the sensor could be combined with, or used in conjunction with another sensor, for example one using the principle of light obscuration.

A second embodiment of the invention is shown in figure 2. In this case, in addition to the features of the first embodiment, a source 11 emits radiation which reaches the receiver 3 along paths 12 predominantly by means of scattering or reflection from the surface 4, or along paths 13 due to particles present within a different part of the chamber from that part in which radiation from source 2 is scattered along paths 7. An additional barrier 15 prevents radiation from reaching the receiver 3 by a direct path from source 11. The radiation output from source 11 is controlled by electronic means 14. Either or both of the radiation outputs from sources 1 and 11 may be adjusted to make the signal received from source 1 substantially equal to that proportion of the signal received from source 11 along paths 12.

The principle of operation is similar to that previously described, except in that the scattering due to particles may be sensed in different parts of the chamber. The presence of particles would only be indicated if similar amounts of scatter were sensed in both parts. In a preferred embodiment, the parts could be partially physically separated, such as to reduce the possibility that a similar signal could result from both parts for example because of an object such as an insect or a spider's web.

A third embodiment of the invention is shown in figure 3. In this case, in addition to the features of the first embodiment, a third source 16, approximately co-sited with source 2, emits radiation at a wavelength which is different from that of source 2. The radiation reaches the receiver 3 along paths 17 predominantly by means of scattering or reflection from surfaces 4, or along paths 18 due to particles in the chamber. The radiation output from source 16 is controlled by electronic means 19. Either or both of the radiation outputs from sources 1 and 16 may be adjusted to make the signal received from source 1 substantially equal to that proportion of the signal received from source 16 along paths 17.

The scattering from sub-micron sized particles, such as those found in typical smokes, is known to be strongly dependent on the wavelength of the radiation in the range 500nm to 1000nm. Because the proportional principle of operation of the sensor allows a stable quantitative measure of the amount of radiation scattered, a significant relative difference in the signals received for the different wavelengths can be a good indicator of the particle size, and this information may be used to effectively discriminate smoke from dust particles.

In order to reduce wavelength dependent errors, it may be found convenient for the reference source 1 to emit radiation at a wavelength intermediate between sources 2 and 16. Alternatively it may be desirable to provide duplicate reference sources (not shown in figure 3), one operating at the same wavelength as source 2 and used in conjunction which source 2, and the other operating at the same wavelength as source 16 and used in conjunction with source 16.

A fourth embodiment of the invention is shown in figure 4. In this case, in addition to the features of the first embodiment, a third source 20 emits radiation which reaches the receiver 3 along paths 21 predominantly by means of scattering or reflection from surfaces 4, or along paths 22 due to particles. The sources 2 and 20 are arranged so that they emit at substantially different angles relative to the axis of maximum sensitivity of the receiver 3. The optical arrangement prevents radiation from reaching the receiver 3 by a direct path from source 20. The radiation output from source 20 is controlled by electronic means 23. Either or both of the radiation outputs from sources 1 and 20 may be adjusted to make the signal received from source 1 substantially equal to that proportion of the signal received from source 20 along paths 21.

The amount of radiation scattered or reflected in a given direction from sub-micron sized particles is known to be strongly dependent on the angle of incidence, for radiation with a wavelength in the range 500nm to 1000nm. Because the proportional principle of operation of the sensor allows a stable quantitative measure of the amount of radiation scattered, a significant relative difference in the signals received for the different angles can be a good indicator of the particle size, and this information may be used to effectively discriminate smoke from dust particles.

The sensor arrangements described in the foregoing text could be constructed using plastic or metal components of suitable design, such as would be obvious to one skilled in the design of light scattering sensors. The sources could employ semiconductor light emitting diodes, such as GaAlAs or GaAs devices widely available from a number of suppliers, which emit efficiently at wavelengths between approximately 600nm and 950nm. The receiver could comprise a silicon

photodiode together with suitable amplification and signal capture means. Silicon photodiodes operate efficiently over a corresponding range of wavelengths and are widely available in different forms from a number of suppliers. It will be obvious that the embodiments described could be combined in a variety of ways, for example using more sources and receivers than described, in order to realise sensors having features for specific purposes.

One preferred method by which the ratio of the radiation outputs from any given pair of sources may be accurately controlled, and by which the signal differences at the receiver may be sensed is to use a microcomputer in conjunction with suitable electronic means. A number of equivalent control strategies may be employed. At one extreme radiation output ratios may be held constant and only difference signals used to estimate the amount of scatter from particles. At the other extreme the difference signals may be maintained near zero, and only the ratio of the radiation outputs used.

In practice, a combination of the two strategies may be best. In either case, there are important benefits in sensing only the difference signals. Because these can be maintained at a small proportion of the signal received from any one source, the stability of the receiver gain becomes relatively less important and the difference signals need not be sensed to such a high resolution. This permits the use of easily available, low cost components for the receiver, its electronics circuitry, and any necessary analogue to digital signal conversion means.

Light emitting diodes convert electrical energy directly into radiation, the intensity of the radiation emitted being approximately proportional to the electrical current which is passed through them. For a given source the main variable which affects radiation output as a function of current is the temperature, a typical coefficient being -0.5% to -1.0% per degree C. However, the co-efficients are generally well matched for a given type of source, and the ratio of the currents can be used to control the ratio of the radiation outputs. A convenient means of achieving this using a microcomputer with pulsed sources is as follows.

The sources are pulsed in a known sequence. Each source is connected electrically in series with a switch, such as a transistor, and the source and switch are connected electrically in parallel with a capacitor. The capacitors are charged in sequence for known times from a switched constant current source, and then in sequence partially discharged through each source while its switch is activated for a known shorter time. For each source an equilibrium is reached in which the same amount of charge flows into the associated capacitor during the charging process as flows through the source when pulsed. By adjusting the ratio of the times for which each pair of capacitors are charged over

any given time period, the ratio of the average radiation outputs of the sources may be very accurately controlled.

The receiver must be able to accurately compare the average amount of radiation which reaches it from the various sources via the various paths. When using pulsed sources the received radiation must be integrated before generating the difference signals. One simple means by which this may be done is to integrate the photocurrent directly on a capacitor with the aid of suitable electronic means, eg a high impedance operational amplifier working in virtual earth input mode with the capacitor in its feedback loop. The current is integrated in one polarity when receiving from one source and in the opposite polarity when receiving from the other source. The net change in the charge on the capacitor is a function of the signal difference.

It should be noted that the use of the methods referred to above, or comparable techniques does not require that the sources should pulse at the same rate or for the same times, only that the constant ratios referred to are maintained. By the use of dissimilar pulse rates and/or charge times very wide variations may be accomodated in the source efficiencies and the net transmission coefficients along the various paths from sources to receiver, whilst still maintaining constant average ratios.

It will be understood that the principles of operation of the light scattering sensor manifestations described are not fundamentally dependent on the details of the electronics circuitry, or on the specification of the components used, and could be realised by one skilled in the art using a wide variety of electronics means. It will also be understood that elements, primarily electronic and mechanical, in addition to those described in the foregoing text would be necessary to construct practical smoke detectors. These would be known or obvious to one skilled in the art of smoke detector design.

CLAIMS

1. A light scattering sensor for sensing the presence of particles in air within a partially enclosed chamber, characterised in that at least two sources and one receiver are disposed such that radiation emitted by a first source reaches a receiver predominantly via a direct path through the chamber and radiation emitted by a second source reaches the same receiver predominantly by means of scattering or reflection from inner surfaces of the chamber enclosure or due to particles present within a part of the chamber, and wherein the ratio of the radiation output from the first and second sources may be adjusted such that the signal received from the first source is substantially equal to that proportion of the signal received from the second source which derives from radiation scattered or reflected from the said surfaces.

2. A sensor according to claim 1 wherein a third source is disposed such that the radiation emitted reaches the receiver predominantly by means of scattering or reflection from the said surfaces or due to particles within a part of the chamber, and wherein the ratio of the radiation output from the first and second sources may be adjusted such that the signal received from the first source is substantially equal to that proportion of the signal received from the third source which derives from radiation scattered or reflected from the said surfaces.

3. A sensor according to claim 2 wherein radiation emitted from the second and third sources reaches the receiver as a result of scattering or reflection due to particles within predominantly different parts of the chamber.

4. A sensor according to claim 2 wherein the second and third sources emit radiation at different wavelengths, such as to cause a relative difference in the signals received where the degree of scattering or reflection due to particles is wavelength dependent.

5. A sensor according to claim 2 wherein the second and third sources are arranged to emit radiation at substantially different angles relative to the axis of maximum sensitivity of the receiver, such as to cause a relative difference in the signals received where the degree of scattering or reflection due to particles is angle dependent.

6. A sensor according to any one of claims 1 to 5 wherein the proportion of the incident radiation scattered or reflected from the said surfaces, as newly manufactured or otherwise in a clean state, is in a known relationship to that scattered or reflected due to the presence of a known concentration of particles having known properties, such as to assist in the initial calibration of the sensor's sensitivity or to assist in monitoring its functioning in service.

7. A sensor according to any one of claims 1 to 6 wherein for a given pair of sources, either first and second, or first and third, the ratio of the radiation outputs may be accurately controlled by a microcomputer in conjunction with suitable electronic means, such that the signals received may be made substantially equal, and wherein the software of the microcomputer uses the radiation output ratio and/or small differences in the received signals to help estimate changes in the quantities of radiation which derive from scattering or reflection due to particles, as a proportion of that which reaches the receiver via a direct path or by means of scattering or reflection from the said surfaces.

8. A sensor according to claim 7 wherein the sources are semiconductor light emitting diodes which emit radiation within the visible or infra-red wavebands between 500nm and 1000nm and are pulsed in a known sequence, and wherein the means by which sources are caused to emit pulses of radiation involves in turn charging capacitors associated with each source for known times and with a substantially identical electrical current, and then in turn discharging for known times through each source part of each accumulated charge, and wherein the ratio of the average radiation outputs from each pair of sources is accurately controlled by adjusting the ratio of the times for which their corresponding capacitors are charged.

9. A sensor according to any one of claims 1 to 8 contained within a mechanical enclosure appropriate for use in detecting smoke resulting from a fire, and into which the ambient atmosphere may ingress either by natural or forced convection, or by forced flow.

10. A sensor substantially as herein described with reference to Figure 1 or Figure 2 or Figure 3 or Figure 4 of the accompanying drawing.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

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Relevant Technical fields

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(ii) Int Cl (Edition 5) G08B 17/103, 17/107

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner
R S CLARK

Date of Search
3.3.93

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	EP 0122489 A1 (NOHMI BOSAI)	
A	EP 0113461 A2 (NOHMI BOSAI)	
A	EP 055319 A1 (COMPAGNIE CENTRAL SICLI) Figure 12 embodiment	

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Category	Identity of document and relevant passages 12.	Relevant to claim(s)

Categories of documents

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